PHYSICAL AND MECHANICAL CHARACTERIZATION OF A WEAK ROCK INVOLVED IN THE EXCAVATION OF AN UNDERGROUND POWER-HOUSE

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A pumped-storage hydroelectric plant located near the village of Solarino, in the province of Siracusa, (Italy), is in an advanced planning stage by ENEL's Design and Construction Department of Venice.

The scheme of the plant involves the excavation of machine and transformer halls inside Mts Climiti mass, which consists of limestone and calcarenite rocks of the Miocene, belonging to the Palazzolo formation.

The area involved in power house excavation includes, from the top to the bottom: medium-grained, slightly cemented whitish biocalcarenites, vuggy-limestones with lateral transitions to calcareous breccia and, more deeply, fine and medium-grained, cemented, white-yellowish calcarenites (Fig.1). During the feasibility study, many investigations were carried out in situ, for the structural and mecha-

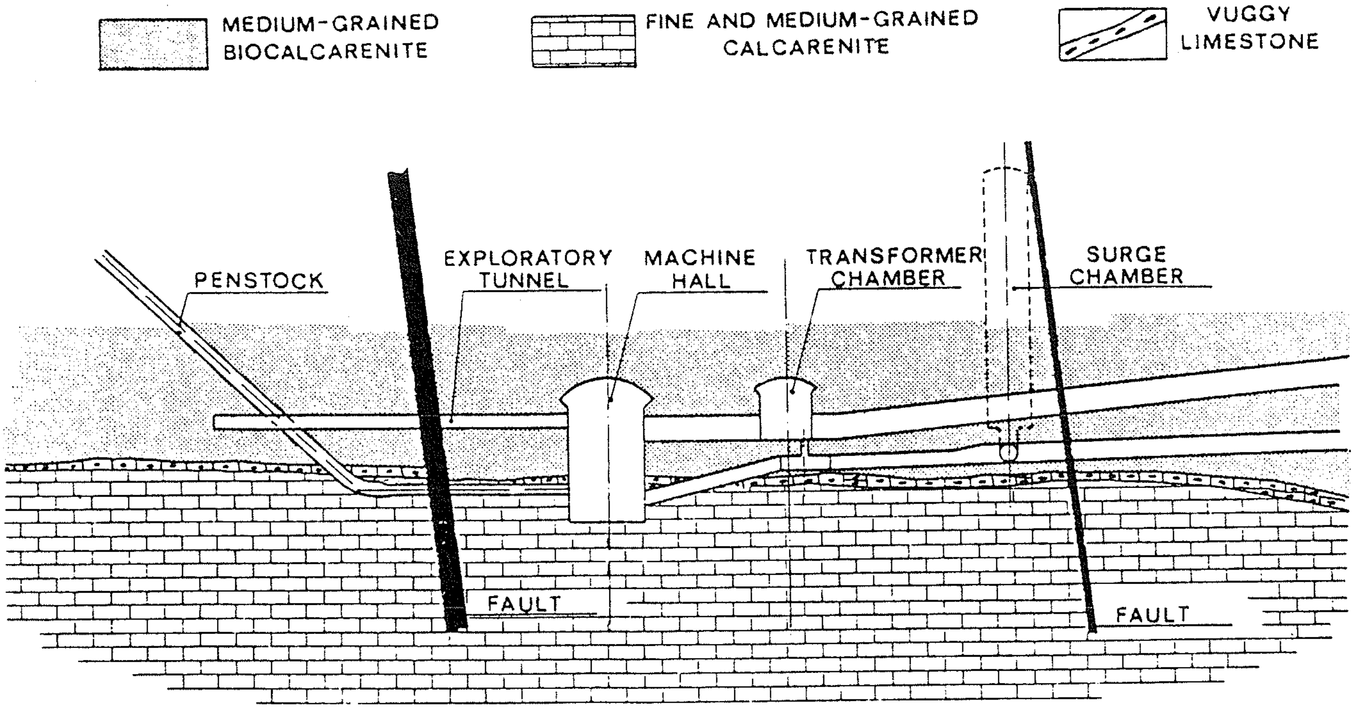

FIG.1 - Geologic scheme

nical characterization of the rock mass, and at laboratory for defining physical and mechanical properties of the various lithotypes.

Laboratory analysis has mainly been developed on the lithotype which will be involved in the powerhouse excavation, that is, on the soft biocalcarenite. Investigations emphasized the importance of textural and structural properties of the rock on the mechanical behaviour, and, especially, a decay process of the mechanical characteristics of water-saturated rock at increasing times.

Surface surveys and photo interpretation indicate that the area is at least concerned with two fault systems, in E-W and N-S direction, respectively. At the powerhouse site, the rock is only involved in the first system of faults, whose planes are characterized by dip α = 80° - 85° and dip-direction β = 190° - 210°. There are, in particular, two zones of tectonic disturbance, which are about 170 m apart, the innermost one being about 15 m thick (Fig.1). The rock mass between the two faults is subdivided into tabular blocks by "closed" and "wide spacing" XX type joints, subparallel to the main faults. The oriented structure of the mass is also defined by subhorizontal "closed" layer joints. To classify the various lithotypes of which Mts Climiti mass are composed, somewhat interesting were the results of laboratory simple determinations performed on integral sample: dry density (ρ_d), sonic velocity (V) and point-load index (I_s). A close functional link of linear type, characterized by high values of correlation coefficients, was indeed observed, within a wide range of physical parameters, between (ρ_d) and (V) (Fig.2) and between (ρ_d) and (I_s) (Fig.3). In particular, as regards the rock involved in the excavation, values of (ρ_d) included between 1.8 and 2.0 t/m^3 were determined. Relevant values of V are included between 3100 and 3900 m/s and values of I_s, between 0.7 and 1.5 MPa. This lithotype has been studied in detail, both as regards textural and mechanical aspects.

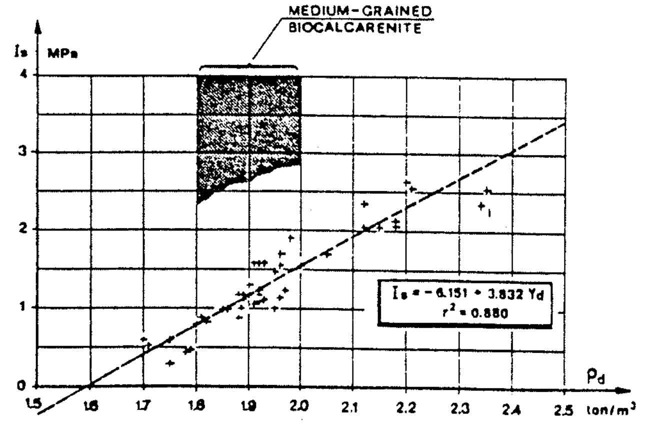

FIG.2 - Plot of point load index versus dry density.

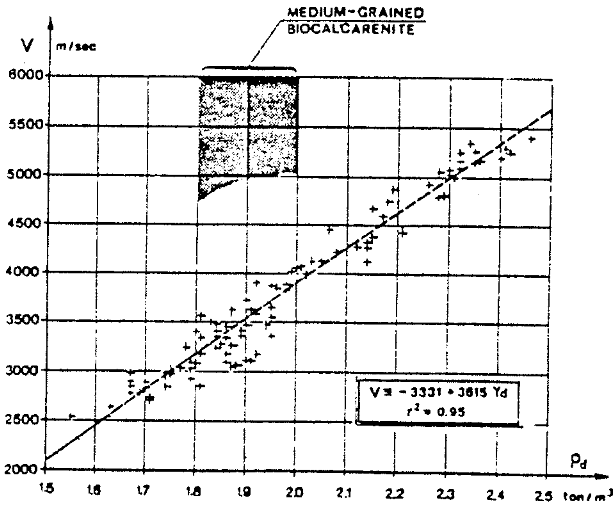

FIG.3 - Plot of velocity of longitudinal waves versus dry density.

The study of thin sections made it possible to classify the rock as biocalcarenite, that is, a lithotype which was formed by heaping up organic remains (complete or broken micro- and macrofossils) and fragments of pre-existing calcitic rocks. The depositing had most likely occurred quite softly, and this resulted in a very great porosity of the deposit itself. Subsequent cementing has only partly destroyed the original porosity, so that the rock has a very low density. Study at the electronic microscope has also shown that the cement is often present in the form of calcite crystals of fairly good dimensions, grown on the primary components of the rock. It is moreover pointed out that the connection points between components are quite infrequent, thus giving rise to a structure which is characterized by a few contact points (Fig.4). Another porosity is added to the one described here, due to the presence of microfossils which have a marked inner porosity (Fig. 5). These interstices are not communicating with one another, and often neither with the outside. A high inner porosity is frequently present in the calcite crystals of fairly good dimensions as shown in Fig.6. The grows of new calcite crystals on the fossil and clast surfaces is clearly shown in Fig.7.

FIG.4 - Typical aspect of porosity in biocalcarenite.

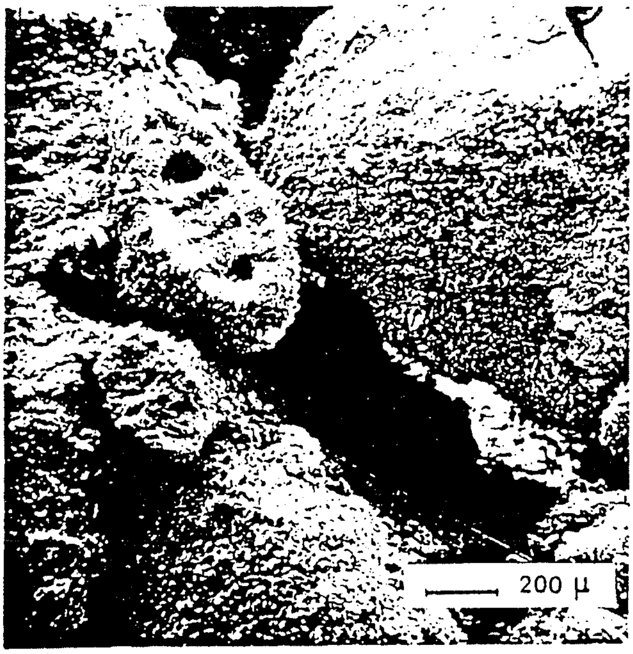

FIG.5 - Microfossil with inner porosity.

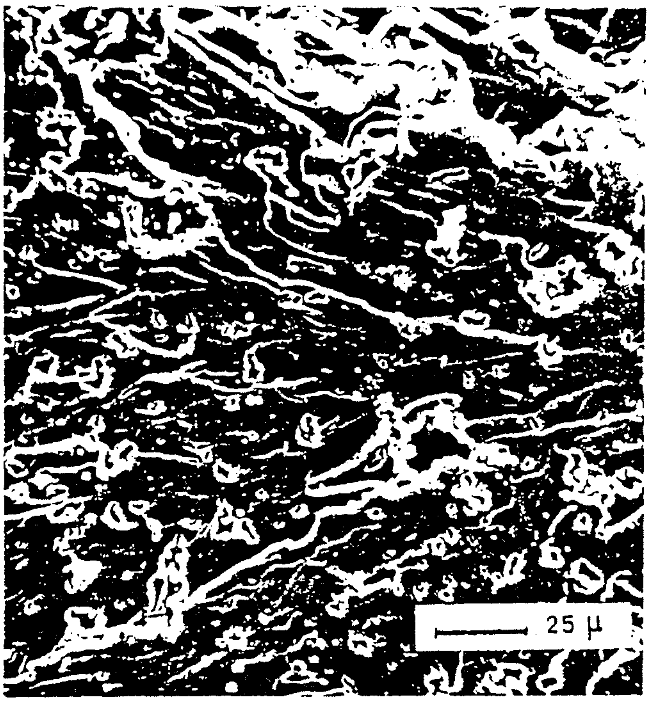

FIG.6 - Example of inner porosity in a calcite crystal.

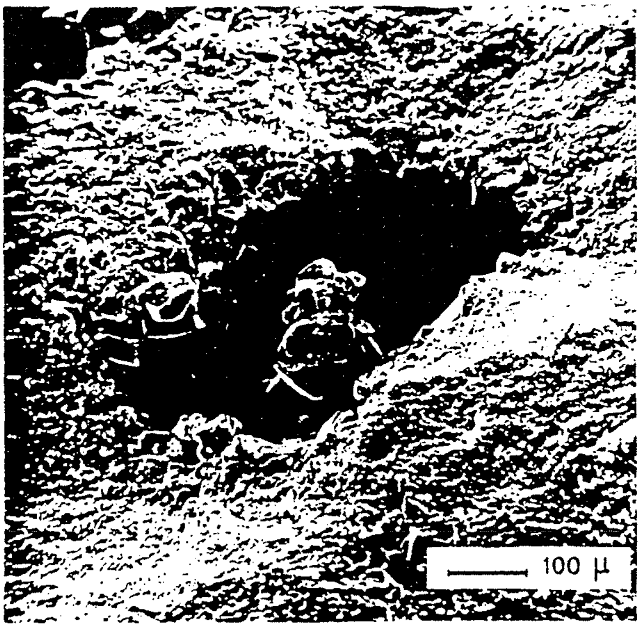

FIG.7 - Example of porosity with growing crystals

Rock, on which unconfined and confined strain-controlled triaxial tests were carried out at constant strain velocity (v = 0.2 μ/s) presents a mechanical behaviour, which is differentiated as to the samples obtained above and below the water table. Fig.8 shows, in a diagram $\sigma_1 - \sigma_3$, peak strength curves for lateral confining pressures of up to 7.5 MPa, while Fig.9 shows typical complete stress-strain curves. It may be pointed out that as the confining pressure increases, differences between strength and deformability properties of the material under dry and saturated conditions tend to decrease. Althought direct measurements of pore-pressures arising during the failure processes were not performed in this study stage, this phenomenon may likely be ascribed to the different dissipation extent of pore-pressures during the isotropic compression phase. It is also interesting to point out that the transition from the brittle to the plastic behaviour of the material is already attained for a confining pressure of about 5 MPa. For further increases of confining pressures, the increase in ultimate axial stress tends to become negligible. The transition from a rock-like behaviour to a soil-like behaviour - typical of porous rocks of the type in question -, checked by isotropic compression tests ($\sigma_1 = \sigma_2 = \sigma_3$), is determined for a stress level of 35 - 40 MPa (Fig.9).

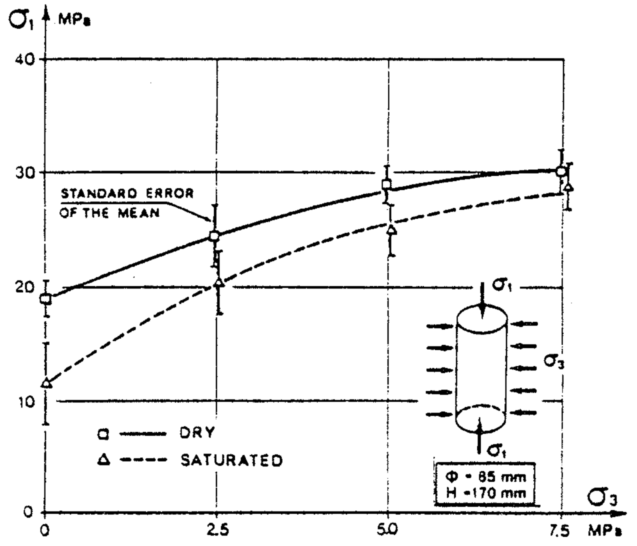

FIG.8 - Triaxial tests on dry and saturated biocalcarenite samples. Failure stress (σ_1) as a function of confining pressure (σ_3).

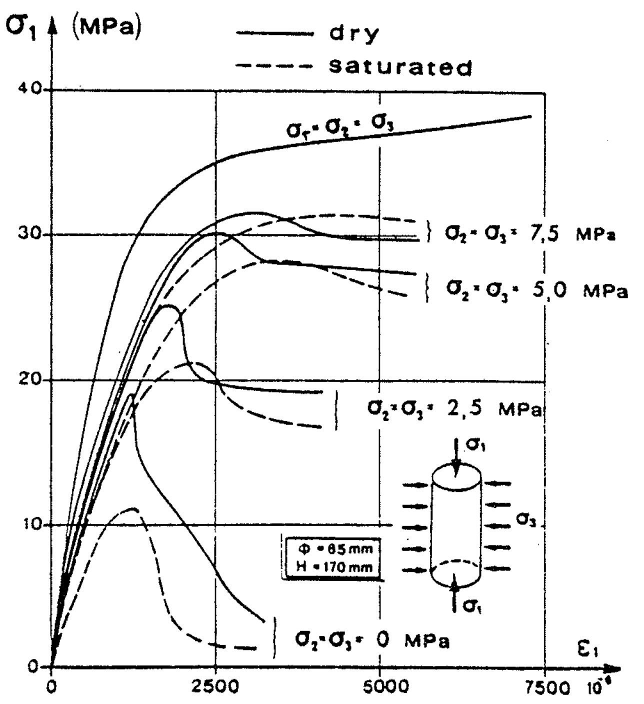

FIG.9 - Complete stress-strain curves for unconfined and confined tests on biocalcarenite samples

The different mechanical behaviour of the samples cored above and below the water table and for which values of saturation degree always lower than unit were measured, has suggested to investigate this question in detail.

The determination of saturation degree (S) was carried out at the laboratory on samples cored above water table and satured at atmospheric pressure at increasing times. Thus, it has been ascertained that, after an initial stage of about 150 days, in which the data (yet increasing) are somewhat scattered (Fig.10), the saturation degree tends to keeping constant attaining a mean value equal to about 0.85. A closed porosity is namely noticed; this had also been observed by means of the electronic microscope (Figs.5, 6). Unconfined compression tests were carried

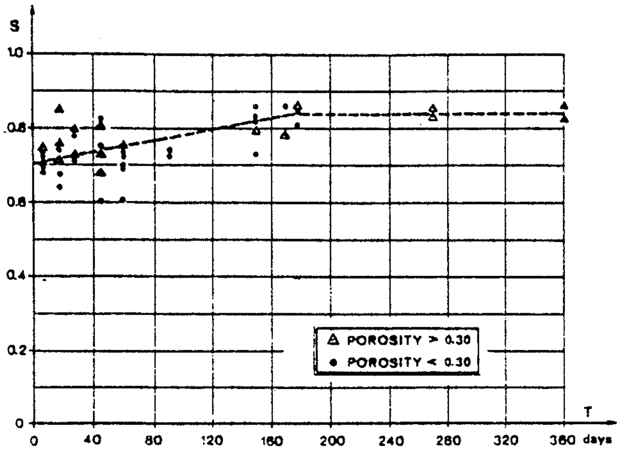

FIG.10 - Plot of water saturation at atmospheric pressure versus time.

out on saturated samples at increasing times. A strength decrease with time, now and then rather marked, has been observed. This decrease seems to confirm the influence of pore-pressures on strength characteristics. Consideration of sample porosity (n), which is maximum and included between 0.30 and 0.33 - when a growth of additional calcite crystals did not occurred on the fossil and clast surfaces - makes it possible to bring-in a further element of evaluation. The tested samples were divided in two classes of porosity, over and lower than 0.30, and the results of uniaxial compression tests on satured samples at increasing times have been distinguished on the basis of this classification.

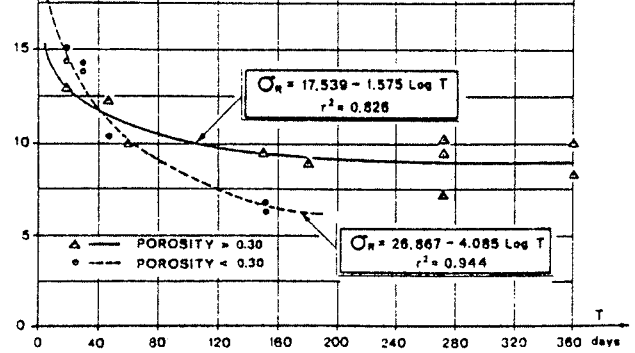

FIG.11 - Effect of saturation time on uniaxial compression strength.

It is ascertained that the decrease in rock strength is more enhanced in samples with porosity $n < 0.30$, as the saturation degree tends to attain the constant mean value. Indeed, from a max value of about 15 MPa after 18 days in water, we go to about 6.5 MPa after 151 days in water.

As regards samples with porosity $n > 0.30$, a strength equal to about 13 MPa after 18 days has originally been measured, whilst strength decrease with time is less marked, reaching about 9.7 MPa after 151 days, and about 8 MPa after 360 days (Fig.11).

As previously pointed out, this decrease in strength is most likely associated with the presence of pore-pressures developing during the test. These pressures have a more marked effect in the case of material having less porosity. In addition to pore-pressure effects, the decay of mechanical strength properties could partly been ascribed to rock alteration phenomena as well.

Technique and nature of these processes are analysed in detail further on in a research which is now being developed.

REFERENCES

Mogi, K. 1970, Effect of the triaxial stress system on rock failure. Rock Mech. in Japan, Vol.1.

Mogi, K. 1971, Effect of the triaxial stress system on the failure of dolomite and limestone. Tectonophysics, Vol. 11, No.2.

Pellegrino A. 1970, Mechanical behaviour od Soft Rocks Under High Stresses, Proc. II Congress of ISRM - Beograd.

Terzaghi, K. 1945, Stress conditions for the failure of saturated concrete and rock.- From the theory to the practice in Soil Mechanics. J.Wiley - New York 1960.

Wyllie M.R.J., Gregory A.R., Gardner G.H.F. 1958. An experimental investigation of factors affecting elastic wave velocities in porous media. Geophysics Vol.23.